Abstract: The section of linear induction accelerator (LIA) with a strong guiding magnetic field (up to 1.5 T), with output beam up to 2 G? and impulse duration 100 ns is created and experimentally investigated. The beam energy gain is equal to 10 keV/cm with the beam current up to 1.5 kA. In LIA it is used annular magnetically insulated cathode with explosive emission; the large length of the beam propagation (1.5 m) without spooling of the beam with high beam energy gain is established. The power microwave radiation about 30-100 MW was achieved from relativistic cherenkov travelling wave tube with high exponential gain on basis of LIA and high-current diode.

1. Introduction

Last time in connection with the problem of linear colliders and compact high gradient accelerators building the great successes were achieved in power microwave radiation amplifiers of centimetre and millimetre wavelength range with relativistic electron beams application. A linear induction accelerator beams were used in the experiments with the microwave power amplifiers in FEI2-[1,2] and in the relativistic klystrons [3,4].

The relativistic cherenkov TWT is attractive in the considered wave range by its simplicity and efficiency. In comparison with FEI, the relativistic TWT has a considerable advantage in space exponential gain (it has a large electron wave coupling coefficient) and it does not demand large electron energies (space exponential gain is inversely proportional to the electron energy).

2. Relativistic TWT on the base of SINUS-5.

Our first experiments with the relativistic cherenkov TWT have been done at the Institute of Applied Physics of Academy of Science USSR (Gorky) with "SINUS-5" [5] - a short pulse accelerator. In this experiments the annular electron beams with 350-600 keV kinetic energy, 0.5+2 kA currents and 5 ns duration were used. The beams were formed by annular magnetically insulated cathode with explosive emission. For beam focusing it was used homogeneous longitudinal magnetic field with strength 10 + 20 kG. The slow symmetric electrical wave Epw of the oversized round waveguide with corrugated side wall have been chosen as an operating one. The input signal at RF wavelength ?=8.24 mm was driven into the operating waveguide through the quasi-optical mirror (Fig.1).

Fig.1. Scheme of the experiment:
1-decelerating corrugated cylindrical -surface waveguide;
2-annular electron beam;
3-magnetic field coils;
4-magnetron;
5-waveguide transmission line;
6-quasi-optical mirror;
7-mirror fastening system;
8 and 10-vacuum windows;
9-microwave absorber.

The space exponential gain in a linear regime is obtained by the formula

\[ \beta = \frac{\pi \sqrt{3}}{2} \frac{c}{\beta^2 - \lambda^2} \]

(1)

where \( \lambda \) (in the experiment \( \lambda \sim 1 \)) is determined by particle-wave synchronism detuning and the beam space charge, \( \beta \) is electron relativistic factor. Parameter \( C \) is an analogue of the classical Pierce's parameter:

\[ C = \left( \frac{4 \cdot \beta^2 \cdot \gamma \cdot c \cdot e \cdot I}{m \cdot c^3} \right)^{1/2} \]

(2)

where \( I \) is a beam current, \( \gamma \) is an electron-wave coupling impedance. The parameter values were varied in the experiments in the range \( C = 0.4 - 0.55 \) by varying \( \gamma \) when the electron beam diameter was changed. The exponential gain gradient and efficiency calculated values were equal to 34 dB/cm and 20 % accordingly. In the experiment when the Pierce's parameter had the smaller value \( C = 0.4 \) the output power had a linear dependece as a function of the input power, but when \( C = 0.55 \) the output power saturation was observed (Fig.2).
The measured exponentional gain gradient corresponded to the calculated values. The total exponentional gain was equal to $K_e = 48 \pm 2$ dB in a linear regime and $K_e = 44 \pm 2$ dB in a power saturation regime. The peak power was equal to $70 \pm 100$ MW with input signal power 4 kW and beam efficiency $6 \pm 11\%$. The radiation pulse duration was close to the current pulse duration 4 ns. The efficiency value obtained by experiment was two times less than calculated one, that can be evidently explained by EHll mode admixture at the level $5 \pm 10\%$ with the basic power that is caused by imperfection of radiation input into the oversized waveguide.

The second run of the experiments that is specified by its greater electron beam pulse duration, have been done at JINR using one section of the linear induction accelerator that had been modified from the section intended for electron-ion ring acceleration.

3. Linear induction accelerator of the annular beam.

The block diagram of the installation is shown in Figure 3.

![Figure 3](image)

Fig. 3. Scheme of the experimental plant.

A modulator (2) drives one section (1) 180 cm long, consisting of 18 inductors. There are two permalloy cores in each of inductor having the dimensions $460 \times 230 \times 25$ mm$^3$. The guiding magnetic field forming system (3) permits to produce the pulse magnetic field with strength $B_z$ up to 15 kG and 1.2 ms pulse duration in the accelerator aperture 170 mm in diameter practically without inductor cores magnetising.

The measured exponentional gain gradient corresponded to the calculated values. The total exponentional gain was equal to $K_e = 48 \pm 2$ dB in a linear regime and $K_e = 44 \pm 2$ dB in a power saturation regime. The peak power was equal to $70 \pm 100$ MW with input signal power 4 kW and beam efficiency $6 \pm 11\%$. The radiation pulse duration was close to the current pulse duration 4 ns. The efficiency value obtained by experiment was two times less than calculated one, that can be evidently explained by EHll mode admixture at the level $5 \pm 10\%$ with the basic power that is caused by imperfection of radiation input into the oversized waveguide.

The second run of the experiments that is specified by its greater electron beam pulse duration, have been done at JINR using one section of the linear induction accelerator that had been modified from the section intended for electron-ion ring acceleration.

3. Linear induction accelerator of the annular beam.

The block diagram of the installation is shown in Figure 3.

![Figure 3](image)

Fig. 3. Scheme of the experimental plant.

A modulator (2) drives one section (1) 180 cm long, consisting of 18 inductors. There are two permalloy cores in each of inductor having the dimensions $460 \times 230 \times 25$ mm$^3$. The guiding magnetic field forming system (3) permits to produce the pulse magnetic field with strength $B_z$ up to 15 kG and 1.2 ms pulse duration in the accelerator aperture 170 mm in diameter practically without inductor cores magnetising.

The measured exponentional gain gradient corresponded to the calculated values. The total exponentional gain was equal to $K_e = 48 \pm 2$ dB in a linear regime and $K_e = 44 \pm 2$ dB in a power saturation regime. The peak power was equal to $70 \pm 100$ MW with input signal power 4 kW and beam efficiency $6 \pm 11\%$. The radiation pulse duration was close to the current pulse duration 4 ns. The efficiency value obtained by experiment was two times less than calculated one, that can be evidently explained by EHll mode admixture at the level $5 \pm 10\%$ with the basic power that is caused by imperfection of radiation input into the oversized waveguide.

The second run of the experiments that is specified by its greater electron beam pulse duration, have been done at JINR using one section of the linear induction accelerator that had been modified from the section intended for electron-ion ring acceleration.

3. Linear induction accelerator of the annular beam.

The block diagram of the installation is shown in Figure 3.

![Figure 3](image)

Fig. 3. Scheme of the experimental plant.

A modulator (2) drives one section (1) 180 cm long, consisting of 18 inductors. There are two permalloy cores in each of inductor having the dimensions $460 \times 230 \times 25$ mm$^3$. The guiding magnetic field forming system (3) permits to produce the pulse magnetic field with strength $B_z$ up to 15 kG and 1.2 ms pulse duration in the accelerator aperture 170 mm in diameter practically without inductor cores magnetising.
Fig. 5. Electron beam images on the target.

electron beam transportation at a great distance when acceleration rate is large.

4. TWT amplifier on the LIA.

The using LIA experiments on microwave power amplification have been done with the following beam parameters: beam energy 500 ± 500 keV, current 0.5 ± 0.7 kA, pulse duration about 60 ns.

The energy increase and electron current decrease as compared with the first run of the experiments led to the Pierce's parameter lowering. However, inspite of this, the possibility of the system self-exitation was higher in the second run of the experiments because of the greater current pulse duration. Therefore for parasitic self-exitation suppression one was forced to use in consist in two sections TWT, microwave absorber providing greater than in the first run of the experiments wave damping up to 10 ± 20 dB. In accordance with calculation in the experiment it have been obtained exponential gain 1.5 dB/cm. If the electron energy have been within the amplification band the microwave pulse duration was close to the current duration. As in the first run of the experiments the output emission on the whole consisted of $E_{0.1}$ wave and small addition of the nonsymmetrical types of waves. Soon after the microwave filter made in the form of cylindrical-surface waveguide section having the longitudinal slots, letting $E_{0.1}$ wave pass and suppressing $H_{m,1}$ waves (in which the slow waves are converted on the matched transition from the corrugated waveguide to uniform one) have been set into the output waveguide transmission line, the radiation power diminished not more than on 5 ± 10 % but the field structure and its polarization began to correspond to the "pure" $E_{0.1}$ wave (Fig. 6). The peak radiation power was 25 ± 30 MW with the exponential gain 35 ± 35 dB and efficiency 10 %.

The made experiments have demonstrated the possibility and relative simplicity of achieving in relativistic cherenkov millimeter wavelength range TWT of large pulse power (up to 100 MW) with the great exponential gain (close to 50 dB).

References


Fig. 6. Picture of the neon-filled lamps annunciation panel glow under the action of the output microwave radiation.